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EFFECTS OF INTERMITTENT STIMULI ON MARKSMANSHIP AND VIGILANCE DURING SIMULATED SENTRY DUTY

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13. ABSTRACT *(Maximum 200 words)*
The purpose of the present study was to determine if the administration of low-level sensory stimuli (odor or vibration) enhances a soldier's speed and ability to detect targets, discriminate friend from foe and accurately shoot at enemy targets during 3 hours of simulated sentry duty. Conditions whereby either the sentry or the experimenter controlled the delivery of the sensory stimuli were evaluated. The odor or vibration was administered intermittently according to one of 3 administration schedules: experimenter-administered, self-administered or stimulus-unavailable. Each subject (n=11) participated in 6 test sessions: (a) tactile stimulus/experimenter-administered, (b) tactile stimulus/self-administered, (c) tactile control/no administration of tactile stimulus, (d) olfactory stimulus/experimenter-administered, (e) olfactory stimulus/self-administered and (f) olfactory control/no administration of olfactory stimulus. During each test session, measures of target detection frequency, target detection latency, friend-foe discrimination and rifle firing accuracy were measured and averaged every 30 minutes for analysis. Additionally, all subjects wore an activity monitor to measure motor movement during each test session. Subjective measures of performance were collected at the end of each test session. For all test conditions and session time periods, target detection frequency did not differ and there were no significant differences of friend-foe discrimination. Further, the periodic administration of a low-level odor stimulus did not enhance a soldier's latency to detect targets. However, administration of a tactile stimulus did attenuate the decrement in detection times found in both odor conditions and in both control conditions. For all test conditions, restlessness as measured by motor activity increased significantly by one hour into the session and remained elevated for the rest of the session. Subjective measures indicated that the 3-hour sentry duty task rated high on physical demand, frustration and overall workload demand.

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This technical report is approved for public release; distribution is unlimited. The views, opinions and/or findings contained in this publication are those of the authors and should not be construed as an official Department of the Army position, policy or decision unless so designated by other documentation. For the protection of human subjects, the investigators adhered to policies of applicable Federal Law CFR 46.

EXECUTIVE SUMMARY

The purpose of the present study was to determine if the administration of low-level sensory stimuli (odor or vibration) enhances a soldier's speed and ability to detect targets, discriminate friend from foe and accurately shoot at enemy targets during 3 hours of simulated sentry duty. Conditions whereby either the sentry or the experimenter controlled the delivery of the sensory stimuli were evaluated. The odor or vibration was administered intermittently according to one of 3 administration schedules: experimenter-administered, self-administered or stimulus-unavailable. Each subject (n=11) participated in 6 test sessions: (a) tactile stimulus/experimenter-administered, (b) tactile stimulus/self-administered, (c) tactile control/no administration of tactile stimulus, (d) olfactory stimulus/experimenter-administered, (e) olfactory stimulus/self-administered and (f) olfactory control/no administration of olfactory stimulus. During each test session, measures of target detection frequency, target detection latency, friend-foe discrimination and rifle firing accuracy were measured and averaged every 30 minutes for analysis. Additionally, all subjects wore an activity monitor to measure motor movement during each test session. Subjective measures of performance were collected at the end of each test session. For all test conditions and session time periods, target detection frequency did not differ and there were no significant differences of friend-foe discrimination. Further, the periodic administration of a low-level odor stimulus did not enhance a soldier's latency to detect targets. However, administration of a tactile stimulus did attenuate the decrement in detection times found in both odor conditions and in both control conditions. For all test conditions, restlessness as measured by motor activity increased significantly by one hour into the session and remained elevated for the rest of the session. Subjective measures indicated that the 3-hour sentry duty task rated high on physical demand, frustration and overall workload demand.

INTRODUCTION

The Weaponeer Rifle Marksmanship Trainer is a device used by the US Army in its basic rifle marksmanship training courses. The Weaponeer utilizes a modified M16 rifle, simulates realistic recoil and presents a variety of stationary, moving and pop-up targets (Spartanics, 1985; 1993). The Weaponeer permits evaluation of both the speed component (accuracy in hitting rapidly appearing pop-up targets) and the variability component (the tightness of the shot group) of M16 rifle firing. Soldier performance on the Weaponeer has been shown to be predictive of live fire performance on the rifle range (Schendel, Heller, Finley and Hawley, 1985). At the U.S. Army Research Institute of Environmental Medicine (USARIEM), the Weaponeer has been adapted for laboratory use in the assessment of soldier performance under varying environmental extremes (heat, cold, chemical contamination) and under procedures (medications, cold weather clothing, chemical protective clothing) designed to protect the soldier from environmental threats (Johnson, 1990, 1991, 1992; Johnson and Kobrick, 1988; Johnson and McMenemy, 1989a, 1989b; Johnson, McMenemy and Dauphinee, 1990; Kobrick, Johnson and McMenemy, 1988). Recent USARIEM research has focused on the evaluation of target detection and rifle firing accuracy during simulated sentry duty (Johnson and Merullo, 1996, 1999, 2000).

When on sentry duty, a soldier must scan a visual field, detect the appearance of targets and accurately discriminate enemy from friendly targets. When an enemy target is detected, the soldier must pick up the rifle, aim and fire accurately at the target. Successful sentry duty performance requires that the soldier maintain (a) sufficient attention to detect targets and to discriminate enemy from friendly targets and (b) sufficient arm-hand steadiness to maintain rifle firing accuracy.

Sustained attention, or vigilance, is impaired by the length of time on sentry duty. In a study by Johnson and McMenemy (1989a), the rifle marksmanship of 8 male soldiers was assessed with the Weaponeer during 3 hours of simulated sentry duty. In this study, the subject had to respond to the infrequent appearance of a target at a simulated distance of 250 meters (12 presentations per each 30-minute time period). When the target appeared, the soldier's task was to pick up the rifle, aim and fire at the target. Target detection time deteriorated with time on sentry duty such that impairments were clearly evident after 60 minutes. However, rifle firing accuracy, or the ability to hit the targets, remained constant over time; soldiers were just as accurate in hitting the targets at the end of the 3 hours of sentry duty as they were at the beginning of the session.

Sentry duty performance may be significantly improved following ingestion of a mild stimulant. Using the three-hour sentry duty paradigm, Johnson and Merullo (1996) studied the effects of caffeine (commonly used to maintain mental alertness) on sentry duty performance. The results showed that 200 mg caffeine (equivalent to about 2 cups of coffee) markedly improved the sentry's target detection latency while M16 rifle firing accuracy was left largely unimpaired. A more recent study shows that caffeine also reduces friend-foe discrimination errors during sentry duty (Johnson and Merullo, 2000).

Other studies have reported that the presentation of certain sensory cues may affect performance on vigilance tasks. Hancock (1984) and Warm (1993) reviewed the effects of environmental stimuli, including noise and vibration on vigilance tasks and concluded that performance under such conditions varies with the nature of the stimulus (type, frequency, and intensity) and the complexity of the task. In many circumstances, environmental stimuli (e.g. noise) can seriously degrade performance. However, under other conditions performance may actually be enhanced by environmental stimuli. Benignus, Otto and Knelson (1975) found that the presentation of continuous white noise degrades performance on visual vigilance tasks while Warner and Heimstra (1971) reported that low intensity, intermittent noise facilitated performance on a complex visual search task. There are few studies examining the relationship between vibration and vigilance performance. Schohan, Rawson and Soliday (1965) reported that target identification and instrument monitoring were unaffected during 3 hours of chronic exposure to low intensity vibrations. However, Poulton (1978) reported that vigilance efficiency may be enhanced following chronic exposure to low intensity vertical vibrations of 5 Hz. In general, exposure to chronic low intensity vibration appears to have little influence on task performance. However, the influence of intermittently presented vibrations on performance has not been fully explored.

There has been recent interest in the possible mood or performance enhancing effects of different odors. A small research literature has emerged to indicate a systematic relationship between olfactory stimuli and performance. Warm, Dember and Parasuraman (1991) reported that performance on tedious vigilance tasks might be enhanced by the intermittent delivery of odors that were previously determined to be hedonically pleasant. The performance enhancing effects were most significant early in the test sessions and were maintained throughout a 40-minute task interval. Similarly, Baron and Kalsher (1996) found that performance on a visual tracking task improved in the presence of a pleasant odor. In both studies, odor delivery was controlled by the experimenter and not by the test subjects. Subjects received the sensory stimuli independent of whether or not they felt that they might have needed it to enhance vigilance. No research has assessed the effect of the test subject having control over the frequency and timing of stimulus delivery.

The above data suggest that under certain conditions the presence of some sensory stimuli (tactile and olfactory) enhance performance on vigilance tasks. In general, performance seems to be enhanced most effectively when the stimuli are low intensity, non-aversive and intermittently presented.

The purpose of the present study was twofold. First, this study assessed the impact of intermittently presented sensory stimuli (odor and vibration) on target detection frequency, target detection latency, accurate friend-foe target discrimination, and rifle firing accuracy of soldiers during 3 hours of simulated sentry duty. Secondly, the study examined the efficacy of two stimulus delivery schedules (experimenter-administered vs. self-administered) on sentry duty performance.

METHODS

DESIGN

The study was modeled on a 2 x 3 x 6 (stimulus type x stimulus administration schedule x time on sentry duty) repeated measures design. The sensory stimulus (odor or vibration) was administered intermittently according to one of 3 administration schedules: experimenter-administered (6 administrations per 30-minute time period), self-administered (ad libitum) or stimulus-unavailable. Time on sentry duty consisted of 6 consecutive uninterrupted half-hour time periods of simulated sentry duty (total session time was 3 hours). In this type of design, each subject served as his/her own control for all 3 factors (stimulus type, administration schedule, and time on task). Based on this design, each subject participated in 6 test conditions: (a) tactile stimulus/experimenter-administered, (b) tactile stimulus/self-administered, (c) tactile control/no administration of tactile stimulus, (d) olfactory stimulus/experimenter-administered, (e) olfactory stimulus/self-administered and (f) olfactory control/no administration of olfactory stimulus. Prior to testing, a determination of sample size (Winer, 1962) indicated that 10 subjects were required for power = 0.90 and alpha = 0.05.

SUBJECTS

Ten male and one female soldier volunteers were recruited from the military test subject population at the U.S. Army Soldier Systems Center (Natick). Only those prospective test subjects with acceptable corrected vision (20/20 Snellen) and olfactory functioning (able to correctly identify the presence of peppermint odorant) were allowed to participate. Prior to participation, all subjects were thoroughly briefed about the purpose and performance requirements of the study. Test subjects who consumed tobacco were permitted to participate in this study, but were not permitted to use tobacco during the test sessions. Subjects were not permitted to consume alcohol during the 24 hours prior to any test session or caffeine during the 12 hours prior to a test session. Additionally, subjects were instructed to be in bed by 2200 hours the night before a test session.

PROCEDURE

Training and Practice Sessions

Training was conducted for 5 days prior to testing. During these sessions subjects were trained on the Model 70 Weaponeer Rifle Marksmanship Trainer (Spartanics, 1993) and wore the standard U.S. Army battle dress uniform (BDU) and components of the Personnel Armor System for Ground Troops to include helmet, armor vest, web belt and full canteen. On training days, each subject assumed a standing foxhole position and repeatedly fired a non-paced series of 9 shots at a scaled 25 meter zeroing target (black E-Type full body silhouette). Once the subject attained a

tight shot group (8 of 9 shots falling within a 4 cm diameter circle), training continued with firing at randomly presented pop-up targets (E-Type full body silhouettes) at simulated distances of 75, 175 and 300 meters. Each 75-meter target appeared for 3 seconds, while each 175 and 300 meter target appeared for 6 seconds. Subjects fired at a series of 32 pop-up targets first with sandbags (supported), then without the aid of sandbags (unsupported). The total number of hits (out of 64) was scored. Subjects were considered trained and ready for testing when a combined (supported and unsupported) pop-up score of at least 41 hits (a marksman rating; Spartanics, 1985) was consistently achieved. All subjects attained or exceeded this performance criterion by the end of the training week. Subjects also participated in abbreviated 15-minute sentry duty sessions (see detailed sentry duty test procedures below) during which twelve 300m targets were intermittently presented. Subjects were exposed to each of the 6 test conditions during these abbreviated test sessions in order to familiarize them with all experimental conditions.

Test Sessions

After training, subjects participated in the 6 test conditions outlined above over six separate days. Parameters for the different test conditions are outlined below.

Test Session Parameters. All testing was conducted between 0730 and 1300 hours. The order of test conditions was systematically varied from subject to subject (using two 6 x 6 Latin squares, cf. Winer, 1962) so that each condition was presented first an equal number of times. Each test session was three hours in duration, during which time the subject assumed a standing foxhole position (supported) and monitored the target scene of the Weaponeer Rifle Marksmanship Trainer. Only the 300m target was presented during all test sessions. The Weaponeer M16A2 modified rifle rested next to the subject at chest height. When the 300m target appeared, the subject's task was to press a telegraph key located next to the soldier's non-dominant hand, lift the rifle, aim and fire at enemy targets only. The time required for the subject to tap the telegraph key served as a measure of latency to detect the presence of the target. Presentation of both friend and foe targets lasted 6 seconds each. Friendly targets were indicated by the illumination of a small red light adjacent to the target during the first second of the 6-second target presentation (Johnson and Merullo, 1999). The presentation of foe targets was identical to that of friendly targets except that the small red light adjacent to the target was not illuminated. The Weaponeer was programmed to provide the subject with immediate feedback. If the subject hit the target, it fell; if the subject missed the target, it remained in view until the six seconds of exposure time had elapsed (then it fell). The total number of target presentations per 30-minute time period was 12 (6 friend and 6 foe, randomly varied), with randomly varied interstimulus intervals of .75, .75, 1, 1, 1, 1.5, 2, 2, 2, 3, 5, and 10 minutes. These interstimulus intervals were the same as those used in earlier studies (Johnson, 1991, 1992; Johnson and McMenemy, 1989a, 1989b; Johnson and Merullo, 1996, 1999, 2000) and the order of their presentation was randomized from time period to time period and from subject to subject.

Odor Stimulus and Delivery. Peppermint odor has been shown to score highly on both alerting and hedonic scales (Warm et al., 1991) and was therefore selected for use in the present study. The peppermint odor was generated and delivered by a 4-channel olfactometer (Knosys Olfactometer, Bethesda, MD) constructed entirely of glass and Teflon ™. The olfactometer was located in a room adjacent to the testing room. A positive pressure stream of clean filtered air was generated by the olfactometer and odor stimuli were intermittently infused into the positive pressure air stream. The air stream flowed continually (0.80 liters/minute) through Teflon™ tubing to the test subject via a nasal cannula. Subjects wore the nasal cannula during experimenter-administered olfactory stimulus delivery, self-administered olfactory stimulus delivery and olfactory control sessions. To verify the delivery of the odor stimulus, a thermocouple was mounted on the nasal cannula to monitor nasal respiration. The odorant was generated by passing clean air into a glass cylinder containing plastic pellets embedded with a peppermint fragrance concentrate (International Flavors and Fragrances, Inc., Union Beach, N.J.). The peppermint odor (a 28% vapor concentration of the surface area of the pellets) was delivered to the test subject via the nasal cannula. This odor intensity was selected because it was determined to be at, or just above, the test subjects' detection thresholds. Each stimulus presentation lasted 30 seconds. For the experimenter-administered olfactory sessions, odors were delivered 6 times every 30 minutes with interstimulus intervals of 2, 3, 4, 6, 7 and 8 minutes for a total of 36 presentations per session. Interstimulus intervals were randomized for each 30-minute time period and each test condition. For the self-administered ad libitum olfactory sessions, odor delivery was initiated whenever the test subject depressed a small button attached to the front of their body armor vest. The frequency of self-administrations was monitored and recorded during the test session.

Tactile Stimulus and Delivery. The tactile stimulus was presented using a modified commercial pager. Subjects wore the pager during experimenter-administered tactile stimulus delivery, self-administered tactile stimulus delivery and tactile control sessions. The pager was firmly attached with a clip to the belt of the test subject's trousers above the left rear pocket. The pager was powered at a level that simulates a partially discharged alkaline battery (approximately 1.0 volt) and generated a sub-audible vibration typical of commercial pagers. The presentation schedule and duration of tactile stimuli for the experimenter-administered sessions were the same as those used for the presentation of odor stimuli. For the self-administered tactile sessions stimulus, delivery was initiated when the test subject depressed a button attached to the front of their armor vest. The frequency of self-administrations was monitored and recorded during the test session.

Performance Measures

Target detection frequency was calculated by summing the total number of detections (based on the subject's responses on the telegraph key), out of the 12

presentations, each 30-minute time period. Target detection latency was assessed by means of averaging the subject's reaction time (time to press the telegraph key) for the 12 targets presented each 30-minute time period. Friend-foe discrimination was measured by summing the number of correct target identifications (number of fires at foe targets plus number of fire-holds when presented with a friendly target) in response to the 12 targets presented each 30-minute time period. Rifle firing accuracy was assessed by examining 2 measures: 1) target hits and 2) shot accuracy. The measure of target hits was determined by summing the number of hits the subject made in response to the 6 foe target presentations during each 30-minute time period. Shot accuracy (Johnson, 2001) was measured by first calculating an average center of impact for the 6 shots at the foe targets per time period. The center of impact was based on the x, y coordinates for each of the shots. Shot accuracy was defined as the distance from the center of mass of the target to the center of impact of the shots.

Galinsky, Rosa, Warm and Dember (1993) have found that the psychological stress of sustained attention is correlated with motor activity and is conceptualized as "restlessness" or "fidgeting." In a study of male and female soldiers, Johnson and Merullo (2000) found that wrist motor activity increased over a 3-hour simulated sentry duty session. In the present study, wrist-worn activity monitoring systems were used to measure motor activity during the test sessions. The activity monitoring system (Ambulatory Monitoring, Inc.) was used to record motor activity at the subject's dominant wrist during each of the test sessions. This activity provided an index for the measurement of stress. The activity monitor is a wireless unit housed in a rectangular enclosure about the size of an ordinary wristwatch. A ceramic bimorph beam inside the enclosure produces a signal at each zero-voltage crossing in response to wrist excursions in any of 3 axes, including small excursions associated with general body movements or changes in posture. These signals are digitized and stored on a board. A clock inside the unit controls run/stop times and specifies the times at which movement occurred. The activity monitor was programmed to record the number of movement signals generated in each 1-minute segment of the vigilance session and was summed every 30 minutes.

Subjective Measures

The USARIEM Environmental Symptoms Questionnaire (ESQ)(Sampson, Kobrick and Johnson, 1994) and the rating scales component of the NASA Task Load Index questionnaire (NASA-TLX) (Hart and Staveland, 1988) were administered at the termination of each daily practice and test session. The ESQ and the NASA-TLX were worded in the past tense to assess individual subjective responses relative to the daily training and testing. Data from practice day 5 served as a control for subjective reports of the 3-hour sentry duty task itself.

The tiredness and muscle discomfort indices of the ESQ were scored according to standard procedures described in Sampson et al., (1994). The NASA-TLX scales for mental demand, physical demand, temporal demand, performance, effort, frustration and total workload were also separately analyzed according to standard procedures (Hart and Staveland, 1988).

After the completion of the 6 test sessions, subjects were asked to rank order each of the test conditions in terms of how much they liked/disliked the particular condition. The ranks for each condition were summed and a mean rank for each condition was calculated.

Data Analysis

Target detection frequency, target detection latency, friend-foe discrimination, rifle firing accuracy (hits and shot accuracy) and activity data were analyzed by means of a 2 x 3 x 6 (stimulus type x stimulus administration schedule x time on sentry duty) analysis of variance with repeated measures on all factors. Each measure was evaluated for treatment effects and Duncan Multiple Range Test post-hoc comparisons of means were performed on measures with significant effects. A probability level of $p < 0.05$ was considered statistically significant. Subjective questionnaire scales (ESQ and NASA-TLX) were analyzed by means of a one-way ANOVA to determine if there were any differences among sessions (including the final practice session) on each of the indices.

RESULTS

TARGET DETECTION FREQUENCY

During each test session, twelve targets were presented at random intervals every 30 minutes. Subjects signaled detection of the target by tapping a telegraph key. Subjects maintained a high rate of target detection frequency (range: 94% - 96%) throughout each of the 6 test sessions. On this measure, there were no significant main effects for stimulus type $F(1,10)=0.21$, $p>.05$, stimulus administration schedule $F(2,20)=0.10$, $p>.05$ or time on sentry duty $F(5,50)=0.38$, $p>.05$. Additionally, the number of targets detected each session did not vary as a function of the order in which test sessions were administered $F(5,50)=.79$, $p>.05$.

TARGET DETECTION LATENCY

When subjects signaled detection of the target by tapping the telegraph key, the latency to detect the target was measured. There were no significant main effects for latency to detect a target due to stimulus type (tactile or odor), $F(1,10)=0.09$, $p>.05$ or stimulus administration schedule (experimenter-administered, self administered or control) $F(2,20)=0.09$, $p>.05$. However, there was a main effect for time on sentry duty $F(5,50)=6.66$, $p<.01$. Post-hoc comparisons indicated that detection times increased significantly after the first 30 minutes on the task and continued to increase over the 3-hour session (Figures 1 & 7a). Further, a significant interaction between type of stimulus, stimulus administration schedule and time on sentry duty was found $F(10, 100)=1.93$, $p<.05$. For each test condition, detection times for the first 30 minutes on task were compared to the last 30 minutes on task. Post hoc-comparisons indicated that target detection latency did not increase significantly for the experimenter-

administered and self-administered tactile conditions but did increase for all odor and all control conditions (Figure 2). Analysis of the self-administered tactile condition data indicated that the number of self-administrations of the tactile stimulus was negatively correlated with the change in detection time over the course of the session ($r=-.72$). That is, the more subjects self-administered the tactile stimulus, the less their detection times deteriorated over the course of the session.

FRIEND-FOE DISCRIMINATION

Correct discrimination of the target as friend or foe was defined as either (a) not firing at a friend or (b) shooting at a foe. On this measure, there were no significant main effects for stimulus type $F(1,10)=0.38$, $p>.05$, stimulus administration schedule $F(2,20)=0.08$, $p>.05$, or time on sentry duty $F(5,50)=0.34$, $p>.05$.

Further analyses were conducted to determine if there was a difference in ability to discriminate friend vs. foe. Analysis of these data indicated that there was a significant main effect for target type (friend vs. foe). That is, across all conditions, subjects were significantly more likely not to shoot at a friendly target (percent correct defined by withholding fire) than to shoot at a foe (percent correct defined by shooting at the target) $F(1,10)=6.21$, $p<.05$. Additionally, target detection latency (reaction time to tap the telegraph key) was significantly shorter for friendly targets (mean = 1.31 sec, S.D. $\pm$ 0.49 sec) than for foe targets (mean = 1.54 sec, S.D. $\pm$ 0.50 sec), $F(1,10)=29.12$, $p<.01$.

RIFLE FIRING ACCURACY

Target hits and shot accuracy data were used to assess rifle firing accuracy. For hits, there were no significant main effects for type of stimulus delivered $F(1,10)=0.32$, $p>.05$, stimulus administration schedule $F(2,20)=2.53$, $p>.05$ or time on sentry duty $F(5,50)=0.64$, $p>.05$. Across all conditions, subjects hit the foe target 54% of the time (mean = 53.99%, S.D. $\pm$ 23.13%, Figure 7b). Similarly, for shot accuracy, there were no significant main effects for type of stimulus delivered $F(1,9)=0.60$, $p>.05$, stimulus administration schedule $F(2,18)=0.23$, $p>.05$, or time on sentry duty $F(5,45) = 0.53$, $p>.05$, (Figure 7c). Using the conversion values supplied by the Weaponeer manufacturer, Spartanics, Inc., each x and y unit is equivalent to 4.68 cm at the 300 meter distance (B. Deutsch, personal communication, May 31, 2000). Therefore, the distance from the center of mass of the target to the average center of impact of the shots (shot accuracy) across all test conditions was calculated as 14.79 cm, S.D. $\pm$ 9.55 cm. A shot accuracy score less than or equal to 23.4 cm at the 300 meter distance is considered functionally accurate (Johnson, 2001). The shot accuracy scores for one subject were not included in the analyses due to incomplete data.

ACTIVITY MONITORING

All subjects wore an activity monitor on their dominant wrist to measure motor movement during each test session. In the present study, there was no main effect for

activity as a function of type of stimulus delivered $F(1,10)=0.01$, $p>.05$ or stimulus administration schedule $F(2,20)=0.04$, $p>.05$. However, there was a main effect for time on sentry duty $F(5,50)=14.31$, $p<.01$. Post-hoc comparisons indicated that activity increased significantly by the second time period (one hour into the session) and remained elevated for the remainder of the test session (Figure 3).

SUBJECTIVE MEASURES

The USARIEM Environmental Symptoms Questionnaire (ESQ) Tiredness Index scores were evaluated and no significant main effect between practice day 5 and test condition days were found, $F(6,60)=0.99$, $p>.05$. An additional analysis was performed to examine main effects for test condition only. No significant main effects were found for scores between type of stimulus (tactile vs. odor), $F(1,10)=0.93$, $p>.05$ or stimulus administration schedule, $(2,20)=0.56$, $p>.05$ and there was no significant interaction of these factors $F(2,20)=0.29$, $p>.05$. The overall mean score across all test conditions for the Tiredness Index was 1.76, S.D. $\pm$ 3.30.

The ESQ Muscle Discomfort Index scores were also evaluated and no significant main effects between practice day 5 and test condition days were found $F(6,60)=1.93$, $p>.05$. Similarly, there were no significant main effects for type of stimulus $F(1,10)=1.37$, $p>.05$ or stimulus administration schedule $F(2,20)=0.79$, $p>.05$, and no significant interaction of these 2 factors $F(2,20)=1.14$, $p>.05$. The overall mean score across all test conditions for the Muscle Discomfort Index was 3.11, S.D. $\pm$ 2.06.

Ratings scores for the NASA Task Load Index (TLX) subscales of mental demand, physical demand, temporal demand, performance, effort and frustration level were evaluated. An overall workload score was also calculated by averaging these component scores. When comparing practice day 5 and each sentry duty test condition, there was a significant main effect for overall workload $F(6,60)=3.18$; $p<.01$ and physical demand $F(6,60)=2.79$; $p<.05$. Post-hoc tests for overall workload indicated that scores for practice day 5 were significantly lower than the 6 test conditions, which did not differ significantly from one another (Figure 4). Similarly, practice day 5 scores for physical demand were significantly lower than all test condition days which did not differ significantly from one another (Figure 5). There were no significant main effects for any of the other subscales. However, the main effect score for frustration was very close to significance ($p< .07$). The post-hoc comparisons indicated that frustration scores were significantly lower for the last practice day than on every condition except the self-administered tactile condition.

Following the completion of all test sessions, subjects were asked to rank order the test conditions (from least=1 to most favorable=6) based on how they liked each condition. Subjects rated the experimenter-administered tactile condition as the test condition they liked best (mean=4.00, S.E. $\pm$ 0.56) followed by the self-administered tactile condition (mean=3.55, S.E. $\pm$ 0.16). The odor control condition was rated least favorably (mean=0.77, S.E. $\pm$ 0.44). These subjective ratings are summarized in Figure 6.

DISCUSSION

Administration of a tactile stimulus during 3 hours of simulated sentry duty significantly attenuated the decrement in detection times found during both odor and both control conditions. Detection times for both self-administered and experimenter-administered tactile conditions during the first 30 minutes of the test session were not significantly different than the last 30 minutes of the test session. Detection times for the four other conditions increased significantly. Additionally, for the self-administration condition, there was a significant negative correlation between decrement in detection times and the number of times a subject self-administered the tactile stimulus. That is, the more frequently a subject self-administered the tactile stimulus the less their detection time deteriorated over the course of the session. Additionally, it is interesting to note that subjects rated the tactile conditions (experimenter-administered and self-administered) as more favorable than the odor and control conditions. During post-session interviews, most subjects reported that they felt the intermittent delivery of the tactile stimulus helped them stay alert and awake. Several subjects reported that they preferred the experimenter-administered condition to the self-administered condition because the delivery of the stimulus had an "element of surprise".

Previous reports have suggested that the intermittent presentation of pleasant odor stimuli enhances the performance of persons conducting tedious vigilance tasks (Warm et al., 1991). These findings were not supported in the present study. Periodic delivery of a low-level odor stimulus did not improve a soldier's target detection latency during 3 hours of simulated sentry duty. Several factors may have contributed to our negative results. Odor intensity in the present study was set at a level determined to be at, or just above, detection threshold while earlier studies have used higher odor concentrations. Because the number of olfactory receptor cells that respond to an odor stimulus increase as odor concentration increases, the intensity of receptor activation is lower when lower odor concentrations are delivered. It is also possible that the intensity of the peppermint odorant in previous studies may have provided a much more significant trigeminal stimulus than that of the present study. Most odorants possess components that stimulate both the olfactory and trigeminal nerves. The degree of trigeminal stimulation increases with odorant concentration. Stimulation of trigeminal nerve receptors in the nose produces a sensation of irritation, e.g. the sharpness of ammonia or the cooling of menthol (Murphy, 1987) that could have contributed to the alerting effects of odor presentation found in earlier reports. Lastly, repeated exposure to the same odorant can produce habituation to that stimulus. Subjects in the present study were intermittently exposed to the odorant for 3 hours compared with earlier studies in which the duration of the vigilance task was less than an hour. For future studies, it may be beneficial to use higher odor concentrations, some of which would clearly produce trigeminal stimulation. Additionally, it might be useful to withhold delivery of odor stimuli until the latter portion of long duration vigilance tasks. This might allow better assessment of whether there is an improvement after introduction of odor stimuli.

The differing results with odor vs. tactile stimuli may be due to conspicuousness of the sensory cue. As discussed above, the odor stimulus was just above threshold

levels. However, the tactile stimulus was well above threshold and its presence was immediately obvious to the test subject. This inequality in psychophysical intensity may have accounted for the disparate results with regard to modality of sensory input. Further, it is possible that enhanced performance may be obtained with intermittent exposure to sensory stimulation independent of sensory modality if the presence of the stimuli is clearly obvious to the test subject.

There were no significant differences in friend-foe discrimination between any condition or time period. However, across all conditions, subjects were more likely to correctly identify a friendly target than a foe. These differences in friend-foe discrimination may be due to the salience of the light cue used in the present study to signal a friendly target. The light cue was briefly illuminated to define a friendly target and may have provided a more obvious signal for the presence of the target. Without the illumination of the light (foe targets) the soldier may have been more likely to miss the appearance of target completely or take longer to respond with firing. The salience of the light cue is supported by the fact that target detection latencies (response time to tap the telegraph key) were significantly shorter for friendly targets than for foe targets. This difference was consistent across test conditions and time periods. The differences in friend-foe discrimination may also be partially explained by the mechanics of the task. Because correct responding to a foe requires not only tapping the detection key but also firing at the target, a subject who does not detect the target quickly may not have enough time to fire before the target falls down on its own. This would increase the number of missed responses to foe targets. The correct response to a friendly target requires tapping the telegraph key then withholding fire. In the case of friendly targets, running out of time to fire actually is scored as a correct target discrimination although the subject may have intended to shoot at the target but ran out of time.

For all test conditions, target detection frequency did not differ. That is, the likelihood of missing a target presentation throughout a given session did not change for any of the conditions. Furthermore, the number of targets detected during test sessions did not deteriorate over the course of session presentations. The subjects detected as many targets the first time they participated in a session as they did by the final test session.

Interestingly, although target detection latency increased as a function of time on task, the number of targets hit and the accuracy of these hits did not deteriorate over the 3-hour test sessions (Figure 7). These findings are consistent with the previous sentry duty reports of Johnson et al. (Johnson and Merullo, 2000; Johnson and McMenemy, 1989a, 1989b). It appears that target detection latency is the parameter most susceptible to change as time on task increases whereas the ability to hit a target and the accuracy of the hit is well maintained over time.

Vigilance tasks are often thought of as boring, tedious and not terribly demanding. Earlier studies have evaluated this quantitatively and found that, in fact, these tasks can be quite demanding, stressful and are subjectively rated as high for overall workload (Warm, Dember and Hancock, 1998; Warm,1993). These findings are supported by the current research. In the present study, all test condition sessions required soldiers to "stand watch" in a simulated sentry duty task for 3 hours whereas practice sessions required them to only "stand watch" for 15 minutes. For all test

conditions, overall workload ratings increased significantly when compared to the last practice condition. Interestingly, the earlier findings of Warm and his colleagues (1998) suggest that the elevation in overall workload scoring was primarily due to the mental demand and frustration components of the NASA-TLX scale. These findings are only partially supported in the present study. Physical demand and frustration scores were elevated following all test conditions but mental demand scores remained relatively constant. These differences may be due to the specific characteristics of each of the vigilance tasks. In the present study, the average time interval between stimulus presentations was quite long compared to earlier studies that used much shorter inter-stimulus intervals. The longer inter-stimulus presentation intervals may account for the lower mental demand score in the present study. Subjects in the present study were required to stand for 3 hours during the test session and this may have accounted for the elevation in physical demand scores.

Increased motor activity has also been associated with time on task and subjective fatigue (Galinsky et al., 1993; Johnson and Merullo, 2000). These studies have reported increased restlessness after approximately 30 minutes on a vigilance task. The present study found that for all test conditions, activity increased significantly by the second 30 minute time period and remained elevated for the remainder of the session. Taken together, these data suggest that long periods of sustained vigilance are highly demanding and substantially taxing to the individual involved.

CONCLUSIONS

Prior studies have repeatedly demonstrated that 3 hours of simulated sentry duty deteriorates a soldier's reaction time and causes increased restlessness as time on task increases. The present study supports these earlier findings and also suggests that the intermittent delivery of a clearly detectable tactile stimulus can reduce reaction time decrements. Under conditions where intermittent low-level odors were presented to subjects, the deterioration in reaction time persisted. The inequality in psychophysical intensity of the two types of stimuli may have accounted for the disparate results with regard to modality of sensory input. Intermittent presentation of a tactile or odor stimulus did not affect the usual increase in restlessness that accompanies lengthy time on task. Likewise, friend-foe discrimination, target detection frequency and rifle firing accuracy were unaffected by stimulus type. Finally, on post-test session measures, soldiers reported that the 3-hour sentry duty task was physically demanding, frustrating and highly demanding overall.

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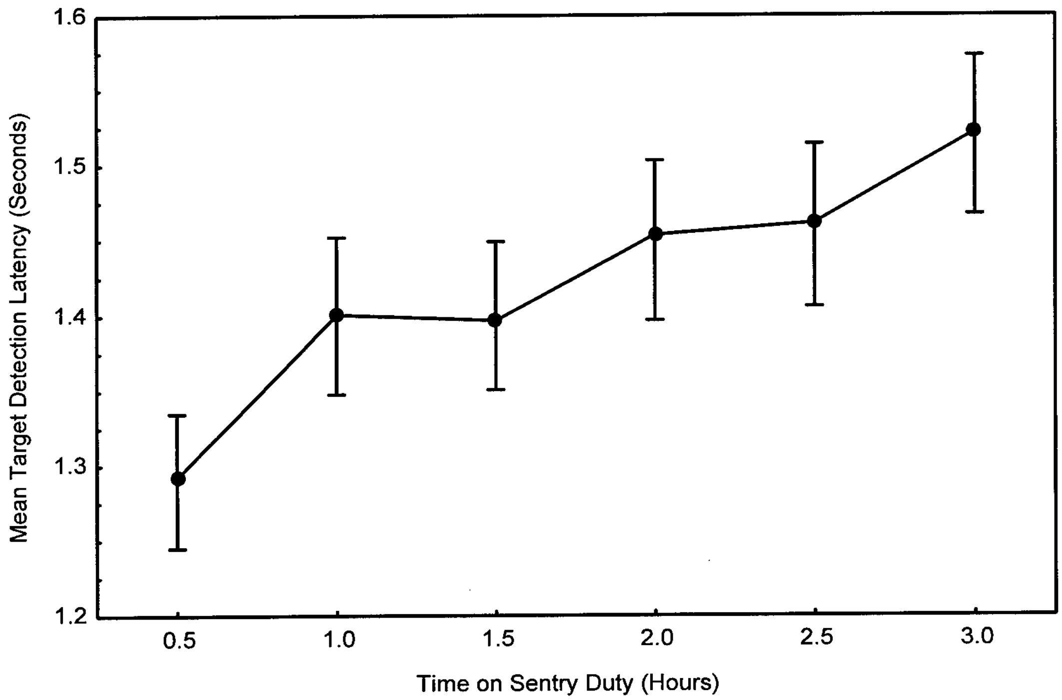

Figure 1: Mean target detection latency and S.E.M. across all test conditions as a function of time on task.

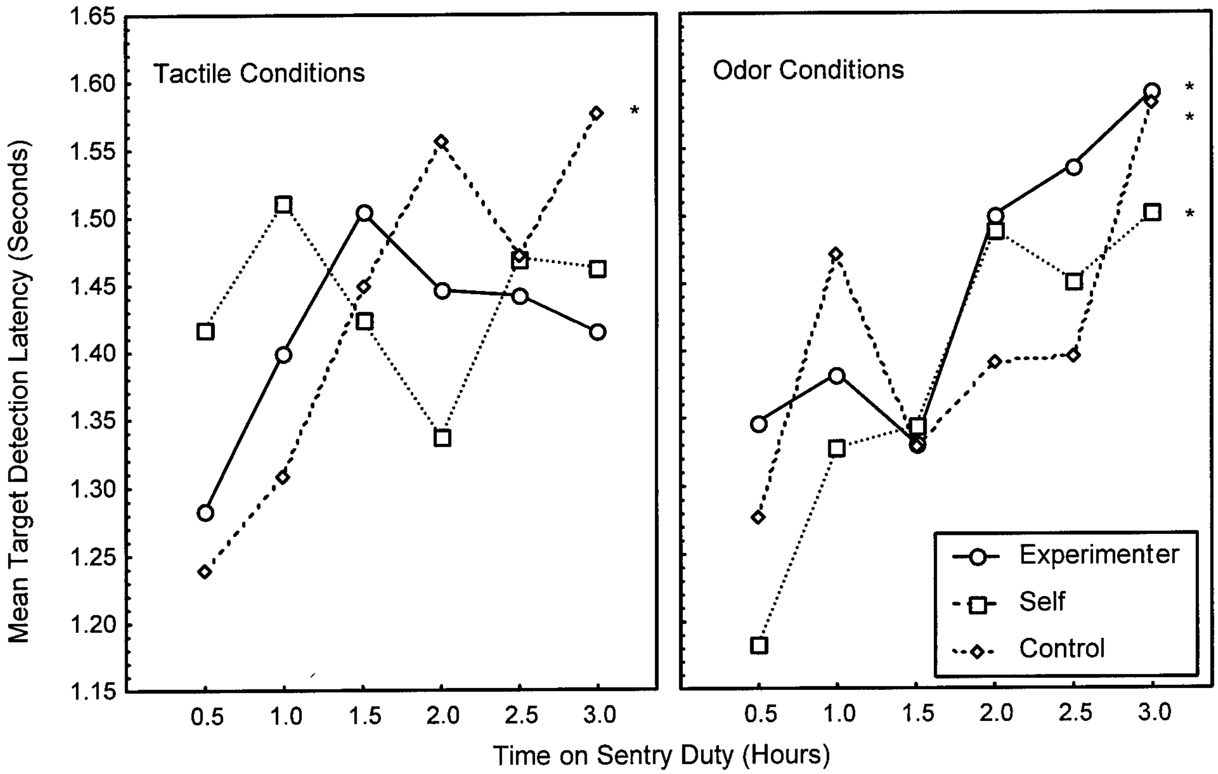

Figure 2: Mean Target Detection Latencies for each of the 6 test conditions. Significant increases in detection time from the first 30-minute time period to the last 30-minute time period are indicated by an (*).

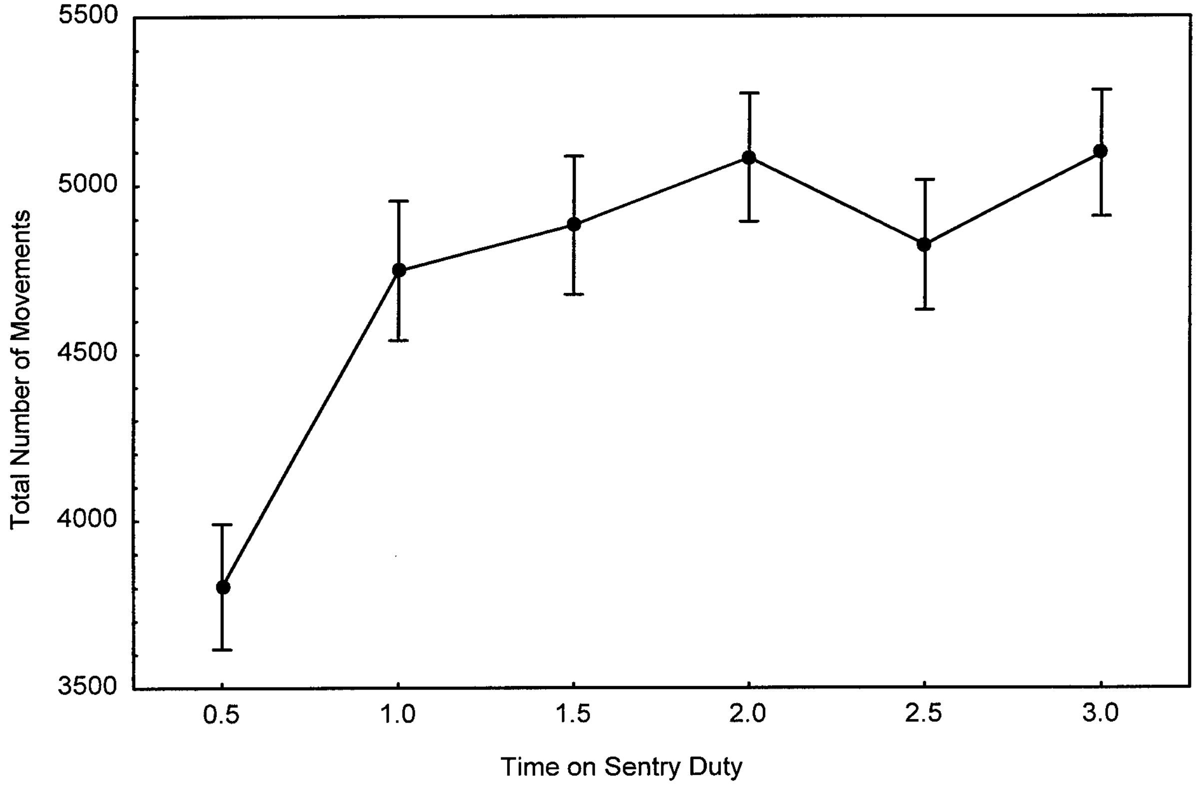

Figure 3: Mean of total number of movements and S.E.M. for all subjects monitored by wrist actigraphy over 3 hours of sentry duty combined across all test conditions.

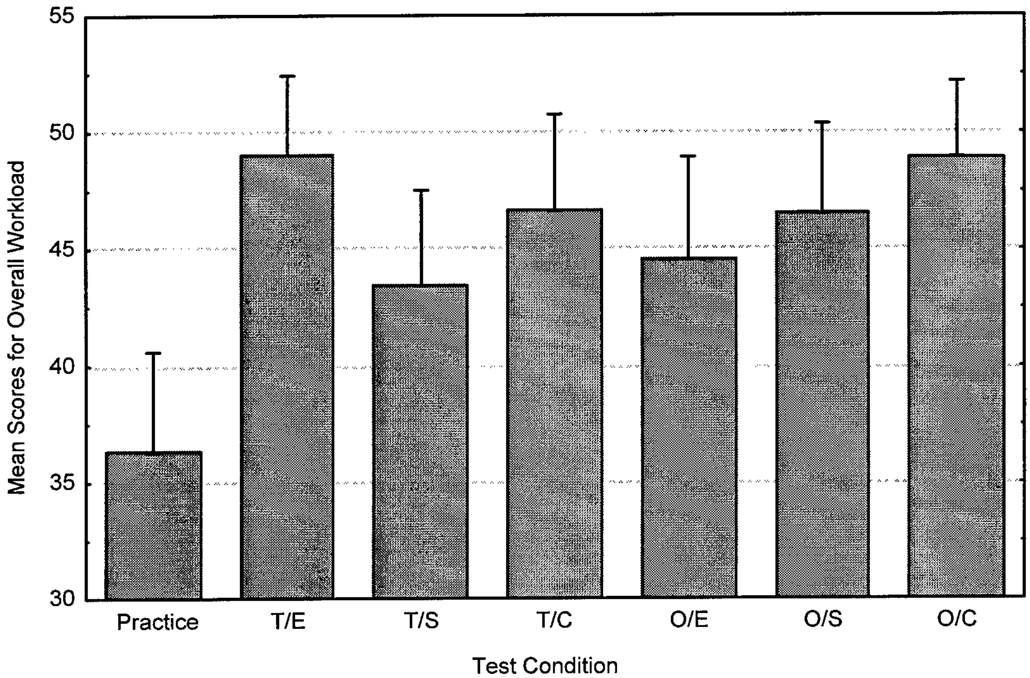

Figure 4: Mean ratings and S.E.M. on the NASA-TLX overall workload scale for the final practice day and each of the 6 test conditions.

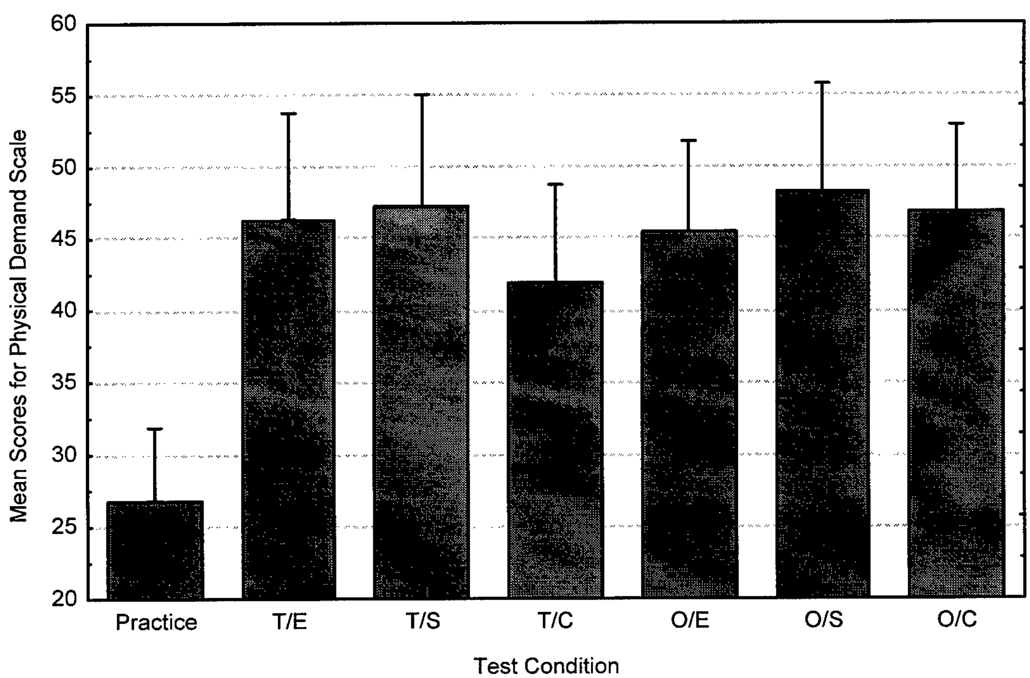

Figure 5: Mean ratings and S.E.M. on the NASA-TLX physical demand scale are presented for the final practice day and each of the 6 test conditions.

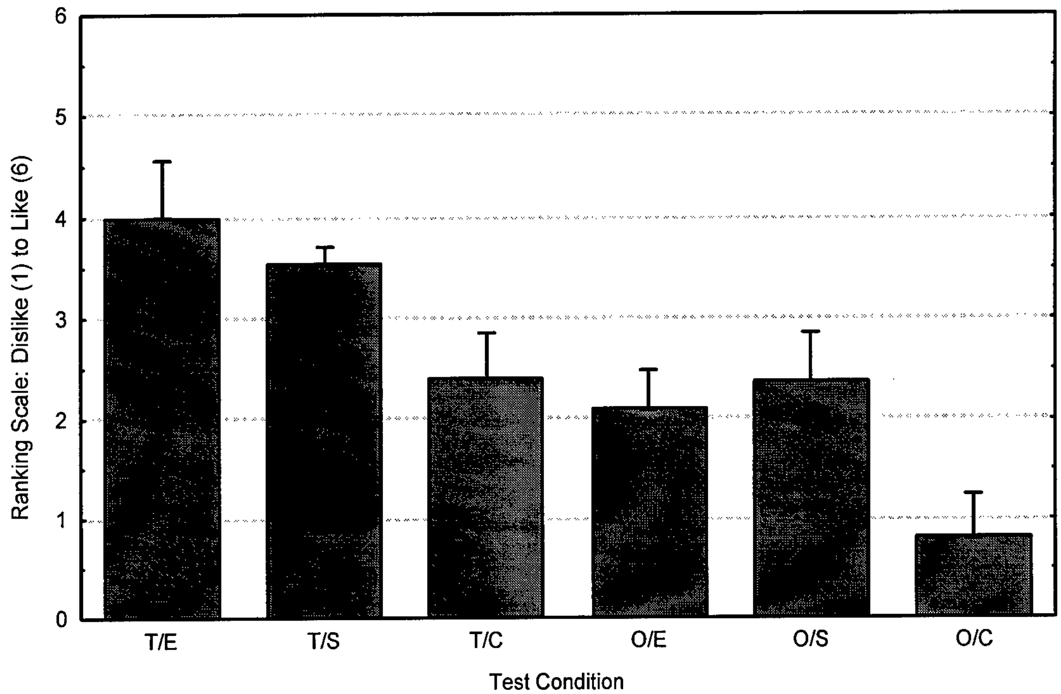

Figure 6: Mean rank ordering and S.E.M. for session preference based on how much subject "liked each condition".

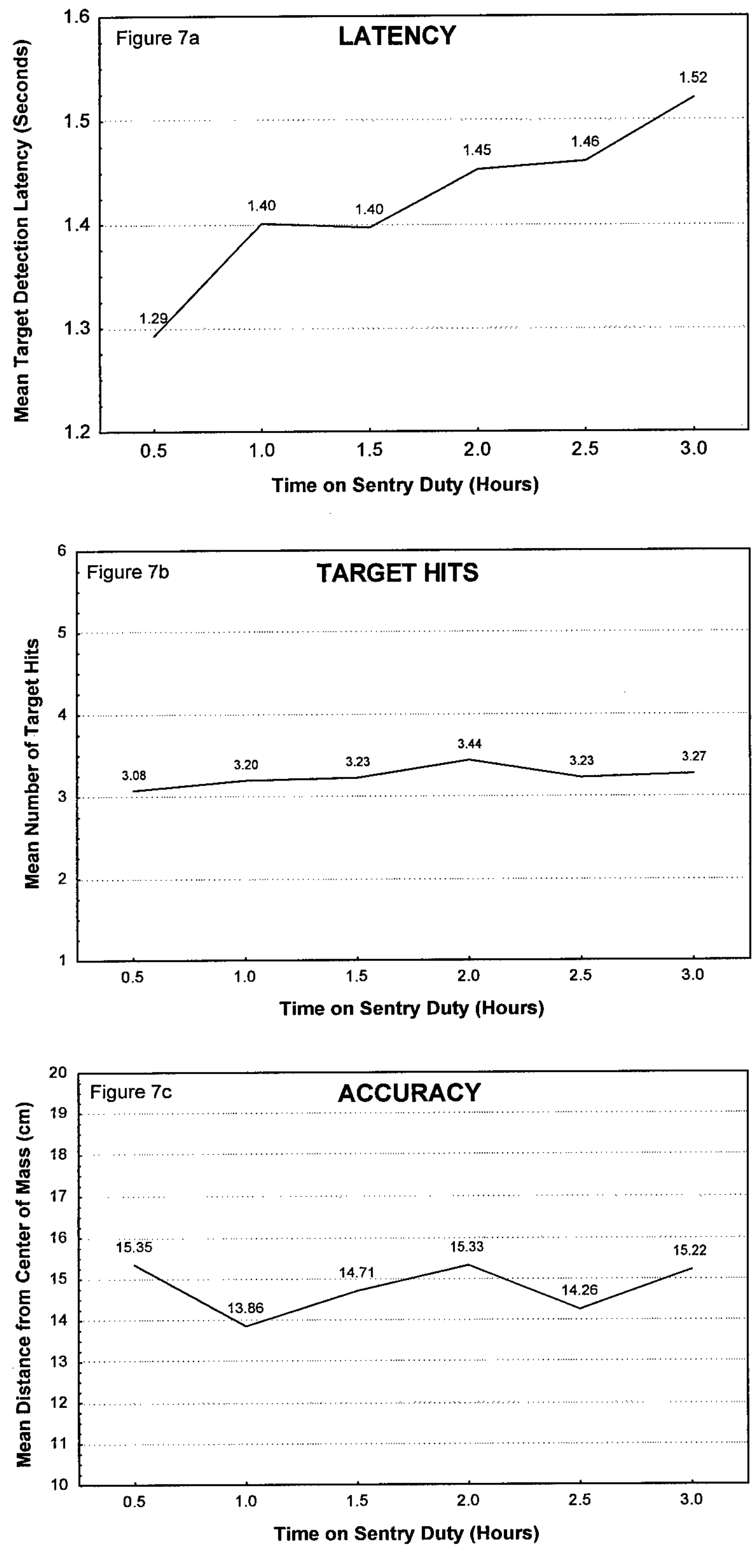

Figure 7: Presented are the detection latency, number of target hits and shot accuracy data collapsed across all test conditions. Data are presented as a function of time on task and are averaged each 30 minutes. Only the latency data changed significantly as a function of time on task.